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NAVAIR Perspective on Corrosion Prevention and Control

By

Stephen J. Spadafora
NAVAIRSYSCOM (4.3.4.1)
Head, Materials Protection Branch
48066 Shaw Rd (Bldg. 2188, Unit/MS5)
Patuxent River, MD 20670-5304

ABSTRACT

Corrosion damage to naval aircraft is a leading cost driver to NAVAIR, which has increased dramatically over the last decade. A major contributing factor to this is the severe corrosive Navy carrier operational environment. Further complicating this issue is the significant aging of the fleet as well as the higher strength materials used for naval aviation due to the carrier landing loads. Finally, increasing environmental and safety restrictions, which limit traditional corrosion control materials, combined with the above, make corrosion a significant factor in NAVAIR's aging aircraft. The Command has initiated a Team wide Aircraft Corrosion Control and Prevention Program to actively address the leading MMH/FH cost drivers and investigate more effective corrosion prevention materials. In addition, concepts such as the integrated maintenance concept (IMC) and condition based maintenance (CBM) will facilitate the use of corrosion prevention and control measures that minimize total ownership costs (TOC) and downtime.

INTRODUCTION

Naval aviation is recognized for its unique and complex set of challenges including carrier battle group and maritime patrol operational requirements, its powerful and pervasive electromagnetic operating fields, and the highly constrained maintenance infrastructure available at sea to combat the effects of the harsh corrosive environment. The Naval Air Systems Command supports over 4100 aircraft; 10,000 engines; and 148 acquisition programs with 96 individual type/model/series. This challenging combination of requirements is further exacerbated by the ever-increasing age of our aircraft and the need to modernize, reduced Operations and Support manpower, and new environmental regulations; all of which have a profound impact how we maintain and support our systems. Virtually every material used on naval aviation aircraft is selected and engineered for the unique maritime operational

requirements and harsh corrosive environment. Several thousand materials are selected and used on each and every aircraft, all of which are tailored to a unique application, but also must provide robust and cost effective life cycle performance. Today, the Navy has recognized that it needs to take a "Total Ownership Cost (TOC)" perspective across the entire life cycle if it is going to meet its long-term mission requirements. This perspective is driving the evaluation, development and acceptance of new technologies, processes and philosophies for naval aviation. The TOC philosophy applies across the entire aircraft life cycle including Science and Technology, Acquisition Engineering and Manufacturing Development, Production, and In-Service Engineering and Logistical Support. Recent TOC studies have indicated that Operations and Support costs are escalating substantially and must be aggressively controlled to make available the resources for new procurements to modernize our forces. Detailed cost assessments have indicated that a significant proportion of this growth is in the areas of aircraft corrosion and inspection.

To specifically address some of these issues, the Command has instituted several broad-based initiatives with targeted missions. These initiatives include The NAVAIR Command-wide Aircraft Corrosion Control and Prevention Program (AC2P2); the Joint Aeronautical Commander's Group (JACG) Joint Aging Aircraft Program and the Command's Aging Aircraft Integrated Project Team (AAIPT); and the Command's Acquisition Environmental Product Support Team (AEPST).

The NAVAIR Command-wide Aircraft Corrosion Control and Prevention Program (AC2P2) is led by NAVAIR's Materials Competency and was initiated to specifically attack the deleterious damage and costs caused by corrosion associated with supporting operational, training, test and reserve aircraft. The AC2P2 Program is focused on the determination of platform specific cost drivers at each level of maintenance. In addition, this program assesses the value of specific maintenance concepts, identifies best practices across the inventory, and targets technology solutions ready for transition. This information is then used to develop and implement plans that apply these solutions in a highly tailored fashion on a platform-by-platform basis. Representatives from NAVAIR, Naval Air Warfare Center's Aircraft Division and Weapons Division, and the Naval Aviation Depots are working together to meet this challenge using state-of-the-art maintenance concepts and technologies making a direct impact on the cost and readiness of our operational forces.

In recent years, the Department of Defense, NASA, FAA, and industry have recognized the need to address the Aging Aircraft situation as it relates our national security and industrial competitiveness. In response to this dilemma, the Joint Aeronautical Commander's Group formed the Joint Aging Aircraft Program. The Joint Aging Aircraft Program is designed to ensure that plans and strategies among the participants are well coordinated and executed effectively and efficiently. The JACG Aging Aircraft Program encompasses four main areas: Air Vehicle, Propulsion, Avionics and Subsystems. The Air Vehicle Area is divided into four sub-components: 1) Corrosion, 2) Non-Destructive Inspection, 3) Repair, and 4) Structural Integrity. The Technical leads or co-leads for each Sub-group are responsible for coordinating information on the efforts that each activity has on going. The Navy has the Lead for the Corrosion Focus Group. Members of each agency or activity participate in joint planning, information exchange sessions and annual conferences to help meet the diverse needs of the community. In March of

1999, the Naval Air Systems Command Officially stood-up the Aging Aircraft Integrated Project Team to address the Commands concerns with aging aircraft. While still in its early stages, this group has pursued identification of issues and resources to address this critical need.

The Command's Acquisition Environmental Product Support Team (AEPST) has membership from across the Commands Competencies. This Team encompasses all facets from Engineering, Logistics, T&E, Industrial, Facilities, through Legal/Contracts. Environmental information and technologies are coordinated with the Programs (PEO's/PMA's) through this group and the individual Program Environmental Process Action Teams. The Materials Competency has a significant role as the leader for Research and Engineering in the area of Environmental Compliance as a member of this Team. The origin of this role is based on the fact that corrosion prevention and control for naval aviation requires the extensive use of materials, which have historically contained hazardous components. For example, organic and inorganic coatings used in protective finishing systems contain hazardous materials such as heavy metals (chromates, etc.) and volatile organic compounds (MEK, etc.) for corrosion protection and material characteristics. These materials and chromates particularly, have been the mainstay of naval aviation's shield against corrosion. Recently enacted environmental compliance regulations such as Executive Orders, Clean Air Act, and Clean Water Act as well as local state and city regulations are now forcing major changes in the materials and processes used to protect our systems. Substitute materials must be developed, engineered and transitioned which perform as well as or better than the baseline systems used today at or below the same costs while meeting these ever stringent environmental compliance mandates.

AIRCRAFT CORROSION PREVENTION AND CONTROL

During Phase One of the AC2P2 Program we conducted squadron surveys of over 20 different aircraft to determine those issues most directly impacting our lowest level of maintenance. These squadron surveys combined with NADEP observations are designed to provide the basis for prioritizing and developing solutions targeted at specific platform needs. As one would expect, areas of dissimilar materials coupled with a propensity for electrolyte collection and/or exposure dominated our findings. Also, areas where corrosion protection was degraded by maintenance procedures and damage, there was a high presence of corrosion damage. Particular areas of concerns were fasteners, grooves and joints where protection schemes had been compromised. Also, many of the alloys used 20 - 30 years ago on navy aircraft were selected with a strong emphasis on performance rather than durability in the corrosive environment. The general philosophy at that time was that the aircraft had a typical life and that regular maintenance overhauls would be sufficient maintenance to preserve and protect our assets until replaced. The reality of today is that the maintenance infrastructure and resources are substantially less than 20 - 30 years ago and aircraft are now expected to be in service much longer than originally anticipated. Maintenance "check-ups" vice overhauls are now the preferred lower cost approach as long as we are able to contain life cycle costs and avoid unnecessary downtime and expenses. However, we are now finding that there is a direct correlation to aircraft age and overall maintenance costs which appears to be consistent across the inventory. We are finding that the Maintenance Man-hours per Flight Hour (MMFH) in fleet

maintenance are increasing significantly and that the nature of that maintenance is also changing. Historically, our corrosion maintenance focused predominantly on maintaining the protection against the harsh environment. Today, we are finding that maintenance man-hours are now principally engaged in the repair area with a corresponding reduction in the time spent preventing corrosion from occurring in the first place. The AC2P2 Program is now assessing the sources of these costs and developing plans to attack the dominating cost drivers in the most efficient and effective manner using state-of-the-art materials, processes, sensors and maintenance practices.

To date we have established a set of Technical Focus Areas including "Corrosion Forms" and a complementary "Solutions Portfolio" in an attempt to bound the problem and identify the potential solutions. Our observations and assessments of operational aircraft have included the full spectrum of corrosion forms.

OBSERVATIONS OF LEGACY AIRCRAFT

Primary Corrosion Types Identified in Phase One

Exfoliation and Intergranular Corrosion. This type of corrosion is of particular concern since left undetected in its advanced form threatens our operational safety due to the potential loss of structural integrity. This type of corrosion has been detected on internal structural members such as rib, spars and bulkheads in addition to structural skins. Early detection of these types of corrosion is critical to ensure operational safety and minimize the extent of accumulated damage before it reaches a critical safety or costly replacement threshold.

Pitting, Crevice Corrosion and Stress Corrosion Cracking. These types of corrosion are of specific concern due to the potential for formation of high stress concentrations, particularly on parts that are highly fatigued and stressed. This type of damage is often difficult to detect and can grow rapidly due to the natural corrosion cell at the crack tip as the precursor to stress induced cracks and eventual corrosion fatigue. Today, predictive techniques that characterize the potential for rapid growth of corrosion pits are not available. This leads us to the challenge of more accurately predicting and controlling aircraft structural degradation and estimating the impact of corrosion fatigue on aircraft inventory availability.

Galvanic Corrosion. Galvanic corrosion has been observed at the interfaces between dissimilar metals which have been exposed to the combined salt water and SO₂ environment. This type of corrosion is prevalent around fasteners, joints and interfaces where the protective sealants and/or coatings have degraded and allow the attack of corrodents.

Surface and Filiform Corrosion. These forms of corrosion are prevalent on exposed surfaces and under coatings that have been damaged or compromised. Manual removal and re-treatment can easily repair this type of damage, but it often leads to excessive damage as maintainers want to make sure that all of the corrosion is removed.

Hydrogen Embrittlement. Hydrogen embrittlement has been seen as the result of inadequate bake-out during maintenance processing as well as the wear or erosion of protective coatings. Techniques to determine local hydrogen concentrations in the maintenance

environment remain unavailable which necessitate overly conservative procedures to ensure its removal.

NAVAL AVIATION CORROSION CONTROL AND PREVENTION INITIATIVES

In Phase II of the AC2P2 Program, the focus is on the development and application of the best technologies to address the identified cost drivers and causes of corrosion. These technologies must reflect the needs of the environmental compliance community while providing affordable and robust corrosion prevention and control. The following is a brief description of some of the technologies under investigation for this effort.

Surface Pretreatments. Surface preparation and pretreatment processes used on Navy aircraft and weapon systems enhance the corrosion resistance and adhesion properties of subsequent organic coatings and are described in MIL-S-5002 "Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapon Systems." A primary thrust in this area is the elimination of hexavalent chromium, which is driven by environmental regulations. This toxic material is the key ingredient in chromate conversion coatings, anodic films and bonding pretreatments because of its outstanding performance as a corrosion inhibitor.

- **Chromate Conversion Coatings (CCCs).** Chromate conversion coatings are the standard pretreatment used in Navy finishing systems. Three categories of CCCs alternatives are being studied: inorganic non-chromated solutions, chromium (III)-based treatments, and sol-gel formulations. The first category includes solutions based on permanganate, cobaltamine, and ceric ion (among others) as the active corrosion-fighting agent. At this time, the performance of these materials is marginally comparable or inferior to conventional CCCs in adhesion and corrosion resistance. A Navy-developed Tri-Valent Chromium treatment has shown corrosion resistance and paint adhesion properties comparable to CCCs in laboratory evaluations; broader testing and in-service demonstrations of this technology are underway. Sol-gel formulations have shown initial promise for favorable pretreatment properties especially for bonding treatments for Titanium. These materials are organic/inorganic polymers based on the hydrolysis and condensation of metal alkoxides.

- **Anodize Processes.** Anodize processes generally provide more protection against degradation than CCC's. Non-chromated anodize alternatives have been developed and transitioned to Navy platforms. These alternatives include: sulfuric/boric acid anodize (SBAA) and thin film sulfuric acid anodizing (TFSA), as well as the standard Type II sulfuric acid anodizing.

Primers and Topcoats. High performance epoxy primers are used on naval aircraft due to their exceptional adhesion and chemical resistance as well as their corrosion resistance properties, especially for aluminum. These materials can be solvent based or water-borne and they have chromated pigments as their primary source of active corrosion inhibition. The performance requirements of standard aerospace epoxy primers are specified in MIL-P-23377, "Primer Coating: Epoxy Polyamide, Chemical and Solvent Resistant" and MIL-PRF-85582,

"Primer Coating: Epoxy, VOC Compliant, Chemical and Solvent Resistant." In addition to the primer, a high-performance topcoat, conforming to MIL-PRF-85285, "Coating: Polyurethane, High Solids," is applied to Navy aircraft in order to enhance protection against the operational environment and to provide desired optical properties. Aliphatic polyurethane coatings are ideal for this application due to their superior weather and chemical resistance, durability, and flexibility.

- **Non-Chromate Primers.** Until recently, chromates were virtually the sole source for active corrosion inhibition in aircraft coatings. This was due to their outstanding performance in protecting nearly all metals in a large range of environments. However, since the use and disposal of carcinogenic chromate containing materials is becoming severely restricted, significant efforts in the development of non-toxic inhibited primers have been performed. Numerous materials have been evaluated in laboratory tests and have shown slightly inferior corrosion resistance performance to the standard systems. However, to attain real world comparisons, the best candidates available to date are under service evaluation on aircraft exteriors (F-18, T-45 & F-15) in a multi-service demonstration effort under the DOD Joint Group for Acquisition Pollution Prevention Program. After over a year of service, the field results have been comparable to chromated primers on almost all aircraft.

- **Self-Priming Topcoats.** An alternative topcoat technology that allows for direct to substrate coating is the self-priming topcoat (SPT). The SPT is a VOC compliant, non-lead, non-chrome high-solids polyurethane coating that was designed to replace the current primer and topcoat paint system used on aircraft. The performance requirements for this material are described in TT-P-2756, "Polyurethane Coating: Self-Priming Topcoat, Low Volatile Organic Compounds (VOC)." The two main advantages to this coating are the reduction of steps in the finishing process and the elimination of the hazardous emissions and toxic wastes that are associated with current aerospace primers.

- **Water-Borne Topcoats.** A new material that virtually eliminates VOC's in aircraft topcoats has been developed and is based on waterborne technology. This new material has shown equivalent characteristics in laboratory testing to the standard high solids topcoat currently used on Navy aircraft. Some advantages of this new topcoat are no VOC's, easy clean-up, enhanced cleanability, and improved application characteristics. A Joint Service technology demonstration is being pursued under support from the Environmental Security Technology Certification Program. Component and full aircraft evaluations are in progress by both Navy and Air Force facilities.

- **Adhesive-backed Films/Appliques.** An alternate exterior finishing system approach, that avoids VOC's from painting operations, involves replacing the topcoat altogether by using adhesive appliqué films. These are flexible films bonded to primed surfaces with an attached adhesive. These adhesive films provide a durable, weather-resistant finish when applied over standard, corrosion-resistant primers. The films can be formulated from polyester, polyurethane, or fluorocarbon resins with acrylic or other adhesives. Application of these films can be done in any enclosed area with minimal training. Nearby personnel can do installation and maintenance work at the same time, since no safety or environmental hazards are present. Initial demonstrations have shown generally good performance from these materials, but have

also highlighted several critical performance areas, which require more investigation. Additional research and more extensive service testing are in progress.

- **E-Coat and Powder Coatings.** Two technologies that are finding new applications in the aerospace industry are electrodeposition coatings (E-Coat) and powder coatings. E-coat is a bath process where charged paint particles are electrically plated to an oppositely charged conductive substrate. During the operation, the paint coats every conductive surface, regardless of shape, with a uniform film whose thickness can be controlled very accurately. The paint film then insulates the substrate, preventing any further deposition of the coating. Cure temperatures for these coatings are typically around 149°C (300°F). Because waterborne coatings are used in the e-coat process, VOC's are kept to a minimum and no elaborate ventilation systems are required, as with conventional spray techniques. Powder coatings can be applied by a variety of methods, including dip coating-fluid bed, electrostatic dip coating-cloud chamber, and the most ideal, spray-electrostatic spray. With electrostatic spray, as the powder passes the high-voltage electrode at the tip of the spray gun, it picks up the electrostatic charge and is attracted to grounded work. There, the powder adheres and will remain until fused and cured in an oven. Overspray is considerable, but it can be collected and reused, so losses are low. Because the material is a solid, there are no VOC's, but an explosion hazard potential exists due to the fine dust overspray. Therefore, careful grounding of the booth and all equipment is required. Small parts, which have been primed with an e-coat and topcoated with a powder coating, have exhibited outstanding protective properties due to the excellent barriers produced by both application technologies.

- **Leading Edge Erosion Protection.** The leading edges and radomes on aircraft have an additional challenge beyond the harsh environment. They must endure the impact of airborne debris, such as sand or rain droplets, during flight. The force of impact from these particles can erode the standard coating systems and adversely affect the underlying substrate. Two technologies are used to address this concern: flexible durable polyurethane rain erosion-resistant coating and elastomeric tapes.

Corrosion Preventative Compounds. A major factor in the deterioration of weapon systems and components is corrosion. The loss of material to corrosion is inevitable, particularly in the harsh Navy operating environment, but the rate of the process can be significantly decreased through the use of corrosion preventive compounds. Corrosion preventive compounds (CPC) provide a temporary barrier against the harmful effects of moisture and corrosive salts. Their value in maintaining an aging fleet of aircraft is increasing important; however, corrosion preventive compounds have seen a decrease in use since the early 90's due to environmental and application concerns. CPC's had previously contained chlorofluorocarbons (CFC's) and petroleum solvents. The CFC's were ozone-depleting substances and the petroleum solvents were classified as VOC's and also listed as Hazardous Air Pollutants. In addition, they had limited ability to be applied to recessed or hard to reach areas. Current CPC's have been reformulated to replace CFC's and eliminate the ozone depleting issue. In addition, CPC's can be applied by methods such as spraying, brushing, and fogging. Furthermore, commercial equipment is now available that allows for efficient and cost effective treatment of aircraft. For example, an airless system has been developed that allows for treatment of recessed and other

areas that are difficult to access. By incorporating new application methodology and consistently treating naval aircraft with CPC's, labor involving corrosion repair can be significantly reduced.

Sealants. Corrosion inhibiting sealants were developed to provide additional corrosion protection beyond that provided by standard aircraft fuel-tank sealants and are described in MIL-S-81733. This military specification covers polysulfide-based sealants which contain soluble chromates and manganese dioxide curing agents. These inhibited sealants were applied to prevent faying surface corrosion and dissimilar metal corrosion and were also applied as intermediate corrosion resistant coatings. While these sealants had excellent application, performance and shelf life properties, in the mid-1990s when the issue of elimination of soluble heavy metal compounds (such as chromates) was raised, alternatives were investigated.

- Polythioether. Polythioether polymers and sealants were also developed under a series of NAVAIR research and development contracts in the 1980s. The polythioether sealants have several advantages over polysulfide types such as faster curing rates and a higher temperature performance range. This effort resulted in a military specification, MIL-S-29574, Sealing Compound, Polythioether, for Aircraft Structures. MIL-S-29574 has a Type II category for a corrosion inhibiting, fuel resistant sealant, but development of corrosion-inhibiting polythioether sealants is in progress.

- SkyFlex. Skyflex is an expanded polytetrafluoroethylene (ePTFE) sealant/gasket material manufactured by W.L. Gore, which is used to replace polysulfide materials in various aircraft applications. Standard polysulfide sealants have several disadvantages, both environmentally and in application/installation. Corrosion inhibiting polysulfides are hazardous materials (hexavalent chromium, HAP solvents) that require mixing before application, masking of surrounding areas, application of a release agent to allow later removal of panels, and can take from 16-72 hours to cure delaying subsequent maintenance operations and/or return to flight. For an average panel, the mixing, masking, mold releasing, sealing, and clean-up steps can take up to 2 hours exclusive of down time for cure and these steps are often repeated each time a panel is opened for inspection/maintenance cycles. In contrast, Skyflex protects against corrosion by providing an excellent environmental seal, contains no hazardous components, does not produce hazardous wastes in application or removal, and requires only very simple installation procedures and no cure time; access panels may be reassembled immediately after application of this sealant. Another principle advantage of Skyflex over current sealants is that it is reusable over multiple panel removals, which reduces the need for frequent reapplication of current sealants (and subsequent mission delays for cure). Current Navy efforts are focused on transitioning Skyflex to all platforms as a preferred spare for polysulfide sealants on access panels, floorboards, and windscreens. Skyflex is currently approved for fleetwide use on access panels of the Navy's P-3, S-3, H-1, E-6, and H-60 platforms, on floorboards for the P-3, H-60, and H-53 platforms, and on windscreens for the H-60. Additional evaluations are currently underway to transition this technology to other platforms. While Skyflex will never replace all polysulfide sealant applications (such as fairing compounds, aerodynamic smoothing), Skyflex is a proven technology for aircraft environmental sealing and offers many immediate benefits over current polysulfide sealants.

HVOF Hard Chrome Replacement. Hard chromium is plated on high strength steels, 4340, 300M, and Aermet 100, that are used in flight critical aviation applications. Chromium plating solutions containing hexavalent chromium, a known carcinogen. Mists containing chromates generated during plating are a major health, safety, environmental, and legal risk. Due to more stringent health, safety, and environmental regulations chromium plating has become economically unfeasible. There are many critical factors to be considered when a coating system is to be used in flight critical applications: fatigue, wear, corrosion performance, etc. One candidate process being pursued is high velocity oxy-fuel (HVOF) thermal spray. HVOF is a line-of-sight thermal spray process used to deposit metal alloy coatings consisting of alloys such as 83% tungsten-carbide 17% cobalt (WC-Co). WC-Co coatings are being evaluated as a replacement for hard chromium plating on high strength steel in aviation applications, particularly on landing gears, hydraulic components, rotary components, and propeller hubs. Demonstration and validation efforts of HVOF deposited WC-Co coatings are ongoing. The Naval Aviation Depots (NADEPs) at Jacksonville and Cherry Point have operational HVOF systems.

Inspection and Characterization. A major cost driver for naval aviation is non-destructive inspection (NDI). This is becoming increasingly important with the aging fleet. The first line of inspection is visual which is very subjective. Beyond this level is a selection of NDI techniques such as eddy current, C-scan, X-ray, etc. Traditional NDI techniques are often labor intensive and time consuming. New advanced techniques that offer better resolution and more rapid characterization are required.

- Thermography. Thermography is a cost effective, rapid, wide-area, nondestructive inspection technique. Advanced infrared thermographic camera systems are employed to detect temperature changes across the surface of structural components. Hidden corrosion, water infiltration, composite delamination, etc. are readily detectable using this technique. As compared to ultrasonic inspection techniques, thermographic inspection is 30 times as rapid, i.e., 30 ft²/min. The technique requires no couplant; it is insensitive to component curvature, uses portable equipment, and can detect corrosion without paint removal. Wide area rapid inspection using thermography is estimated to save the F/A-18 E/F Program several million dollars over its life cycle.

- Ultrasonic Guided Wave Sensors. A breakthrough in ultrasonic testing has been achieved by modifying an Infrared CCD camera to image sound waves. Physical contact is achieved between the camera imaging chip and a water tank, and the sound waves are focused using plastic lenses. Fine corrosion pits in thin aluminum sheet, fibers in multi-layer composites, blood vessels in hands, and fine fatigue cracks have been clearly imaged using sound energy transmitted through the test object. Sound energy introduced from the same side as the camera has been used to image corrosion on the backside of the plate (without direct physical access to the back of the plate). Work is presently focused on design of a handheld test head for service use.

- Advanced Eddy Current. An advanced eddy current inspection system developed by Jentek Sensors is being evaluated for application as a fatigue monitoring system. Experiments are being performed to determine if the system is capable of detecting conductivity changes

associated with cumulative fatigue damage. The goal of the experiments is to show that the method can be used to "measure" the fatigue life expended of aircraft structures in real time.

Sensors and Detection. The knowledge of functional and structural integrity of an aircraft is vital for readiness, reliability and survivability of a military mission. The management of corrosion on an aircraft system (structures, mechanical components and avionics) requires a complex scheme of controls and protective measures which must be periodically reviewed for their effectiveness. Corrosion affects all areas of aircraft in some magnitude and occasionally in a catastrophic manner when a load bearing part fails. Corrosion of aircraft systems is often found in difficult to access areas. The following are examples of such areas: hidden structures, avionics bay and boxes, crevices and grooves (fastener holes, butt-joints, leading and trailing edges of wings, configurational and structural overlaps etc.), pockets (structural voids, access panels, fill holes, hidden spaces etc.) and dissimilar material junctions. Since hidden areas are difficult to inspect without major teardown, corrosion damages remain undetected, and thus necessitate a frequent (periodic) maintenance and overhaul. An ability to assess corrosion damage as it occurs is very useful when adopting a Condition Based Maintenance (CBM) philosophy.

- **Intelligent Thin Film Wireless Sensors.** A wireless Corrosion Monitoring System (CMS) has been developed that measures corrosivity and can easily be installed in a variety of military and commercial structures. The CMS is based on thin film bi-metallic galvanic sensors capable of in-situ corrosivity monitoring. The CMS is used to monitor both the corrosivity of the enclosed volume of space where the sensor is located and corrosivity of any liquids present on the surface of the sensor. They have been successfully demonstrated on stored aircraft, test panels exposed on aircraft carriers, military bases and on ammunition stockpiles stored in silos. Proper placement of the corrosion sensor can permit the detection of sealant, gasket, and other barrier material failures. Installation/operational parameters have been developed to effectively monitor environmental corrosivity without affecting flight operations. The correlation of the corrosion sensor output to specific observed levels of corrosion will permit the generation of Maintenance Cues, which can drive condition based remedial maintenance actions.

- **Aircraft Fiber Optics "Nervous System" (CBM).** The objective of the fiber optic sensor effort is to develop and transition sensor systems that will ultimately allow us to move from a Safe Life maintenance philosophy to a Condition Based Maintenance (CBM) philosophy. As our fleet ages beyond its original design life, operational costs will continue to escalate as dictated by the ever shrinking inspection intervals and/or expanding downtime intervals. The need to move away from a Safe Life maintenance philosophy towards a Condition Based Maintenance (CBM) philosophy is imperative if we want to reduce life cycle costs while maintaining fleet readiness. Various types of fiber optic sensors exist such as Fiber Fabry-Perot (FFP) interferometer, Tapped Bragg Gratings (TBG), Long Period Gratings (LPG), Bi-Conical Tapered (BCT) Fibers, etc. Each type of sensor has its advantages and is finding new military and commercial uses. Preliminary work is being conducted to determine the survivability of fibers under fatigue as well as determining the optimal adhesive.

Protective Coating Removal. During the life cycle of military aircraft, paint stripping and re-coating is required periodically for inspection, maintenance and repair, as well as for changes

in paint schemes and special purpose coatings. Approximately 1000 rotary and fixed wing aircraft are stripped in Department of Defense (DOD) Depots each year. Historically, chemical paint strippers formulated with methylene chloride have been used on aircraft surfaces. In addition, to enhance the stripping of tough epoxy and polyurethane coatings, phenol activators were added. Chemical stripping is labor intensive, time consuming, and frequently requires additional sanding and scraping followed by extensive rinsing. Paint removal operations at the Naval Aviation Depots (NADEPs) are one of DOD's greatest sources of hazardous waste, requiring increasingly expensive treatment and disposal procedures. The elimination of chemical stripping of aircraft with methylene chloride and phenols is aimed at meeting the goals of the Clean Air and Clean Water Acts, the Resource Conservation and Recovery Act (RCRA), and the National Emission Standards for Hazardous Air Pollutants (NESHAP).

- **Plastic Media Blasting.** Plastic media blasting (PMB) is a mature, production ready process, which is more environmentally friendly than chemical stripping and reduces operator exposure to health hazards. The Navy issued a specification for "Plastic Media for Removal of Organic Coatings", MIL-P-85891. Of the seven types of media described in the specification, Type V (acrylic media) has the potential for safe and efficient removal of coatings from Navy aircraft and is in use at the NADEPs. A recent addition, Type VII (starch-acrylic) is a product that can be used to blast fiberglass structures without damage to the substrate. The PMB process was approved by the Naval Air Systems Command for use at depot level activities to remove paint from aluminum airframe surfaces of 0.016" minimum thickness and from composite laminate aircraft surfaces of 0.073" minimum thickness. While PMB is well suited for aircraft paint stripping, significant amounts of waste are generated and the process does not meet the environmental goal of minimizing hazardous waste.

- **Non-Hazardous Chemical Strippers.** Early alternative candidates for methylene chloride based paint strippers included acid or alkaline-activated benzyl alcohol-based removers and N-methyl pyrrolidone (NMP)-based removers. Of the three, the alkaline-activated benzyl alcohol products have demonstrated the greatest potential for general use on naval aircraft. Acid-activated removers have limited application due to their corrosive effect on magnesium and the potential for embrittlement of high strength steel components such as landing gear, tail hooks, fasteners, and wing attachment bolts. NMP paint removers are most effective at elevated temperatures (160 to 180°F), and thus more suitable to tank stripping operations. Approval for limited use of benzyl alcohol based non-HAP paint removers has been granted for three non-HAP chemical strippers to be used at five sites on seven aircraft platforms. In addition, a non-HAP paint remover specification TT-R-2918 "Remover, Paint, No Hazardous Air Pollutants (HAPs)" was developed and released in early 1997. One area of concern with the alkaline-activated materials has been the significant increase in application time required for stripping. Field service evaluations of the alkaline-activated stripper conducted at Naval Aviation Depot Jacksonville (NADEP JAX) confirmed this concern. Recently, hydrogen peroxide-activated benzyl alcohol strippers have been evaluated to increase stripping efficiency; however, implementation is hampered by excessive corrosion rates for magnesium, titanium, and cadmium-plated steel and by waste handling concerns related to gas evolution in waste containers. Continuing efforts with these non-HAPs paint removers has yielded some promising results to address these concerns.

- Flash Lamp/CO₂ Removal. The FlashJet coating removal system reflects a synergistic coupling of two diverse approaches (Xenon Flashlamp/Carbon Dioxide (CO₂) blasting) to perform aircraft paint removal. Neither method, when viewed alone, allowed for safe and effective coating removal from aircraft substrates. Flashlamp coating removal was deemed unacceptable due to lamp reliability, soot residue, and substrate heating, and CO₂ pellet blasting was found to be extremely slow, as well as potentially damaging to composite and thin aluminum skins. McDonnell Douglas Aerospace (MDA), currently Boeing St. Louis, developed and patented Flashjet® which combines the flashlamp-induced coating volatilization followed by the sweeping motion of the low pressure CO₂ particle stream which acts as a soot remover, lamp cleaner, and substrate cooler. Two primary systems have been developed: a gantry system and a mobile manipulator system. The FlashJet robotic gantry system has been installed at two locations: NAS Kingsville, TX for re-work of T-45 aircraft and Boeing Mesa, AZ for re-work of Apache Helicopters. These systems are well suited for small to mid-sized aircraft. A Mobile Manipulator FlashJet System was demonstrated at NADEP Jacksonville for use on a P-3 and is well suited for stripping large aircraft.

SUMMARY

The Naval Aviation challenge remains as one of the most unique and complex balances of optimum engineering design and support. The efforts of the JACG Aging Aircraft Program, the AC2P2, the AAIPT and the Environmental Program must be fully coordinated to provide the optimum impact to our operational as well as production systems. This requires state-of-the-art technologies to prevent premature degradation and failure with a severely constrained maintenance environment, increased operational tempo, and shore-based support infrastructure. In general, the message is simple: The Fleet is getting older, and becoming much more costly to operate and support. Corrosion is a major cost driver for naval aviation. Finally, Operations and Support costs directly impact the ability to modernization the fleet. The Command's resources must be focused to sustain existing assets most affordably while directly impacting the performance and affordability of new systems across their life cycle.